

DISTORTION
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IN
AUDIO AMPLIFIERS

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DISTORTION DUE TO REFLECTIONS IN AUDIO AMPLIFIERS

In long lines such as telephone lines there is distortion due to reflections unless the input and output impedances are made equal to the characteristic impedance of the line. When the line is properly terminated the impedance of the generator is equal to the impedance of the load. This is also the condition for maximum output. It has been shown by Brown¹ and Warner and Loughren² that in the case of an audio output tube working under the condition of no distortion due to curvature and grid currents the maximum undistorted output is obtained when the load impedance is made twice that of the tube.

This paper is a report of an attempt to determine if it is possible to detect distortion due to reflections in the usual tube circuit. The usual tube circuit consists of the tube and the load with the usual B supply. We have the generator connected to the load by means of a short line whose length perhaps is infinitely short.

In a long line if there are reflections there will be a variation of the potential along the line due to the combined potential of the reflected and transmitted disturbance. In the extreme cases when the conditions are properly adjusted we find nodes and antinodes. If the line has zero length and there are reflections the reflected and transmitted waves will arrive at the point in question at the same time and will combine giving the same potential at all points along the line (zero length) and there will be no distortion detected. If there are no reflections or if the line

1. Brown, W. J.

Discussion on Loud Speakers

Proceedings of Phy. Soc. 36 p. 218 1923-1924

2. Warner, J. C. and Loughren, A. V.

Output Characteristics of Amplifier Tubes

Proc. Inst. Radio Eng. 14 p. 735 Dec. 1926

has zero length the virtual voltage should be constant at all points and at all times for any given load. If there are no reflections the voltage is simply the voltage of the transmitted disturbance. For zero length of line if there are reflections the voltage is the combined voltage of the reflected and transmitted waves, but the sum is constant at all points and is independent of any phase or time shift along the line.

If there is a variation of voltage from point to point, such as at either end or at the middle of the load, then there are reflections and the change of voltage between the points is an indication of the distortion produced by reflections. Such variations of voltage indicate that the line length of the plate circuit of the output tube is not zero but some fraction, $\Delta\lambda$, of a wave length.

Two methods were employed to determine whether reflections can be detected in a line $\Delta\lambda$ in length. In the first, Method "A", the comparative voltage for equivalent sections was determined throughout the length $\Delta\lambda$. The second, Method "B", attempted to make comparative voltage measurements of similar sections by the introduction of a time shift (phase change) along a horizontal axis as compared to a fixed vertical axis. In each case a Western Electric Cathode Ray Oscillograph No. 224 B was used as the voltmeter. The photographic records made of the length of the swing, (vertical in photographs) are proportional to the potential across a portion or across all of the load resistance.

METHOD "A"

(Equivalent sections tapped off load resistance.
See Fig. 1)

If the plate load in the output circuit of an audio amplifier is great enough to produce reflections at either or both the input or output ends, and the length of this load resistance is equivalent to a length $\Delta\lambda$ of the impressed wave λ then the virtual voltage for equivalent sections taken throughout the length of this resistance should have different amplitudes.

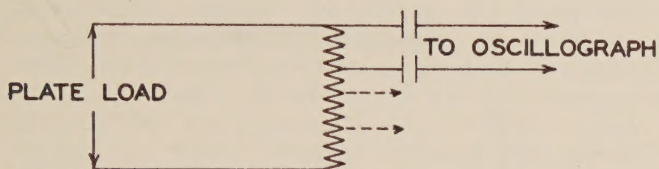


Fig. 1

Due to the possibility of a standing wave made up of the original wave and reflected waves being symmetrical at opposite ends of the load resistance it might be better to take equivalent sections near one end and the middle of the load resistance. In order to more nearly "view" all parts of the fractional wave length $\Delta\lambda$ from one end to the middle it might be well to section the load resistance in such a way that the parts bear to the total resistance ratios such as the following: - $1/3$, $1/6$, $1/2$; $1/4$, $1/4$, $1/2$; $1/8$, $3/8$, $1/2$; etc.

Apparatus and Procedure

A beat note audio oscillator was coupled to a two stage transformer coupled audio amplifier as shown in Fig. 2. The plate load of the second tube was made of two sections, AC and DF. The load AC was kept in the plate circuit of this tube by the commutator switch S_1 . A section AB of the load resistance AC was coupled to one pair of deflector plates of the cathode ray oscillograph by means of commutator switch S_2 and either the "insulating" transformer T or the condensers C_1 and C_2 . For convenience in adjusting the plate load, DF was made in two sections, DE and EF. Switches S_4 and S_5 made the removal of DE and EF possible. By means of the switch S_1 the potential across AB was placed across the deflector plates when the resistances were in the order, reading down in figure A, B, C, D, E, F. With S_1 reversed the order was C, B, A, D, E, F. A biasing battery was connected to the second pair of deflector plates of the oscillograph to center and shift the pattern on the viewing screen of the oscillograph.

A camera which reduced the pattern to about two-thirds its original size was focused upon the viewing screen in order that a photographic record of the patterns might be obtained. By means of S_1 the section AB could be made either the high or low end of AC. This means of making the shift along AC insured that equivalent sections of the resistance AC were used. Commutator switch S_2 was used to impress the voltage from AB upon C_1 and C_2 without change of direction. It was found necessary to use S_2 when condenser "insulation" was used, as a reversal of the potential through AC resulted in a different reactance in C_1 and C_2 . This was due to the ground connection which produced an inequality between the vertical and horizontal plates in the cathode ray tube. Unless S_2 was used to impress the alternating potential from AB on T without change of direction at T, a relative linear displacement of the patterns resulted.

Two exposures were made on each photographic plate. After the sections of the two resistances AC and DF were in place, one exposure of the alternating potential impressed on the deflector plates was made. The switches S_1 , S_2 , S_3 were then reversed and a second exposure made. A number of pictures at various loads was made for the tubes used. In some of the earlier pictures DF was zero, but in later pictures AC and DF were kept approximately equal until excessive loads were used. The value of AB was governed by the ratio desired between AB and BC, and the length of the pattern impressed upon the viewing screen of the cathode ray oscillograph.

The data in TABLE I will indicate the various combinations of the load when the frequency was 2500 cycles and 8000 cycles per second. The photographs corresponding to Table I are given in PLATE I_A. Data was taken at various frequencies in the audio band. Space does not permit giving more than a sample set.

An attempt was made to obtain pictures with both capacity and transformer "insulation" between the section AB of the plate load and the oscillograph. Due to reactance (parallel resonance, probably) of the capacity "insulation" upon the plate circuit the section AB of the plate load became several degrees warmer.

TABLE I

Tube	Plate Resist- ance	Plate Volt- age	Grid Bias	Freque- ncy (Approx.)	Load A B	Load B C	Load D E	Load E F	Total Load	Type Insulation	No.
	ohms				ohms	ohms	ohms	ohms	ohms		
RCA 171A	1800	135	-16½	2500	200	600	1000	0	1800	Transformer	41
"	"	"	"	"	400	1750	1500	0	3650	"	39
"	"	"	"	"	2,250	10,400	22,000	0	34,650	"	45
"	"	"	"	"	2,250	10,400	22,000	7,900	42,550	"	48
"	"	"	"	"	2,250	7,900	22,000	10,400	42,550	"	49
"	"	"	"	"	2,250	10,400	22,000	5,400	40,050	"	50
MX 112A	5300		-12	8000	900	1,500	3,000	0	5,400	"	53
"	"	"	"	"	900	1,750	2,500	200	5,350	"	54
"	"	"	"	"	1,250	3,500	5,400	1,000	11,150	"	55
"	"	"	"	"	10,400	20,000	100,000	0	130,400	"	58
"	"	"	"	"	10,400	100,000	20,000	22,000	152,400	"	59
"	"	"	"	"	10,400	22,000	20,000	100,000	152,400	"	60

This heating effect was not apparent when transformer "insulation" was used. It was further observed that the reactance for capacity "insulation" depended upon the way the alternating potential was impressed upon the variable air condensers C_1 and C_2 . Even when S_2 was placed in the circuit and the potential impressed upon C_1 and C_2 the same way, the reactance differed. Therefore, all pictures considered reliable were made with transformer "insulation." Unless proper polarity of the secondary is observed in transformer T, the same unequal amplification is observed upon reversing switch S_1 that was observed when C_1 and C_2 were in the circuit. S_2 was required with transformer "insulation" if the two lines on each picture were to be properly aligned for ease in comparison of lengths.

A few pictures made with widely different plate loads are shown for an RCA 171 A tube and an MX 112 A tube. Pictures Nos. 41, 53, 54 are shown for loads approximately equal to the plate resistance of the tube used. The lengths of the two exposures on each picture are practically the same. Pictures Nos. 39, 55 are shown for plate loads approximately equal to twice the plate resistance of the tube used. Again, whereas there may be a slight difference in the lengths of the two lines shown on each of the pictures, that difference is very small. Pictures Nos. 45, 48, 49, 50, 58, 59, 60 were made for excessive loads. Pictures Nos. 45, 48, 49, 59 show a measurable difference in lengths of the two lines on each picture. Picture No. 50 had the sections of the plate load in such ratio that the two positions investigated had practically the same resultant amplitude. Picture No. 60 shows the two lines nearly equal in length but with a slight linear displacement.

The approximate percentage of the difference in lengths of the lines as compared to the longer line on the picture is given for a few pictures.

PLATE I_A

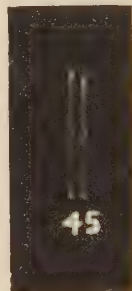
*Pictures From RCA 171 A Tube
Resistance of tube 1,800 ohms.



+R = 1,800 ohms
‡f = 2,500 cycles



R = 3,650 ohms
f = 2,500 cycles



R = 34,650 ohms
f = 2,500 cycles



R = 42,550 ohms
f = 2,500 cycles



R = 42,550
f = 2,500 cycles



R = 40,050 ohms
f = 2,500 cycles

*Transformer insulation used for all pictures.

+R is load resistance

‡f is frequency in cycles (approx.)

PLATE I_A (Continued)

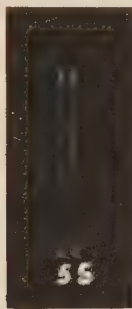
*Pictures From MX 112 A Tube
Resistance of tube 5,300 ohms.



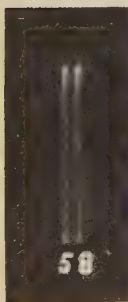
+R = 5,400 ohms
+f = 8,000 cycles



R = 5,350 ohms
f = 8,000 cycles



R = 11,150 ohms
f = 8,000 cycles



R = 130,400 ohms
f = 8,000 cycles



R = 152,400 ohms
f = 8,000 cycles



R = 152,400 ohms
f = 8,000 cycles

*Transformer insulation used for all pictures

+R is load resistance

+f is frequency in cycles (approx.)

Picture No.	Length of longer line	Length of shorter line	Difference in length of lines	Per cent of Difference
45	2.17 cm.	2.10 cm.	0.07 cm.	3.2
48	1.83 cm.	1.62 cm.	0.21 cm.	11.5
49	1.83 cm.	1.75 cm.	0.08 cm.	4.4
59	2.70 cm.	2.53 cm.	0.17 cm.	6.3

METHOD "B"

(Horizontal time shift obtain electrically)

By this method an attempt was made to shift the "voltmeter" along the "line" by introducing a phase shift or time shift on the horizontal plates of the cathode ray oscillograph as indicated in Fig. 3. The "insulating" 171 tube was used at all times. When the horizontal component of potential was not wanted the 371 A tube was turned off. Thus the load on the oscillator was constant.

Transformer T_1 gave considerable trouble. Various transformers were tried before one that gave a stable pattern was found. By means of T_1 and T_3 the phase changing circuit was electrically "insulated" from the circuit under test. By means of the "insulating" 171 tube changes were made in the phase changing circuit without disturbing the test circuit. In order to prevent coupling between circuits each circuit was screened and had its individual B battery supply. The camera used to obtain the photographic record was so constructed that pattern and picture were practically the same size. In order to eliminate outside disturbances all the apparatus was screened with one inch mesh wire fencing. There was room inside this screen for the operator to work without disturbing any of the apparatus.

Since both pairs of deflector plates of the cathode ray oscillograph were coupled to the same beat note oscillator, a standing pattern was obtained on the viewing screen of the oscillograph. This pattern remained stationary even though the frequency of the oscillator drifted a few cycles. It was necessary to have a standing pattern since the light from the 224 B tube was not intense enough for an "instantaneous" photograph.

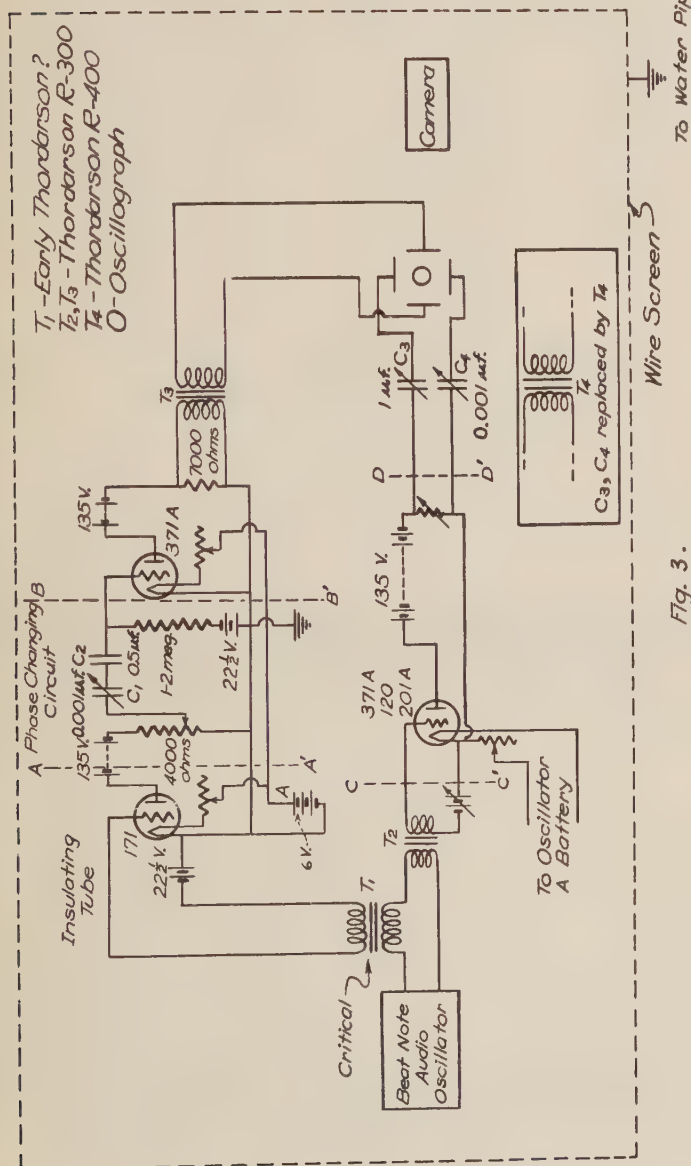


Fig. 3.
Diagram of Apparatus
Circuit between CC' and DD' is the circuit being tested.
Circuit between AA' and BB' is the phase changing circuit.

Circuit between CC' and DD' is the circuit being tested.
Circuit between AA' and BB' is the phase changing circuit.

A series of pictures was taken at various plate loads, ranging from plate resistance to several times plate resistance, for three tubes: a CX 371 A, a DX 120, and a UX 201 A. The first two tubes were chosen because they can stand relatively large grid swings, and the third because of its high amplification constant. The grid bias of each tube was made of a magnitude to insure operation on the straight part of the tube characteristic. The grid swing was not permitted to become great enough to introduce grid currents. The grid swing was never greater than $2/3$ of the usual maximum value.

In taking pictures three exposures were made on each plate. In order to have a reference line for analyzing purposes an exposure of the vertical component of the pattern was made. This exposure was made by opening the A battery circuit of the output tube, 371 A in figure, following the phase changing circuit. The second exposure was made of the elliptic pattern formed when the A battery circuit described above was closed. The third exposure was made of the pattern after it had been rotated through thirty to forty-five degrees by varying the capacity, C_1 , in the phase changing circuit. The circuit under test was not disturbed during the time required for the three exposures.

For analyzing purposes a pair of axes was made by taking separate exposures of the vertical and horizontal components of the potential impressed upon the two pairs of deflector plates. (Due to space not included).

The data in TABLE II is a fair sample of data taken in METHOD "B". Photographs in PLATE I_B correspond to TABLE II on the following page.

In order to study the pictures taken it was necessary to draw two reference lines on each picture parallel to the horizontal component of potential impressed on the deflector plates of the oscillograph. In drawing these two parallel lines care was taken not to mark over any part of the pictures.

A few representative pictures are shown with the type of "insulation" used for tubes CX 371 A and DX 120. Pictures from the UX 201 A were not reliable because of the small output voltage obtained due to the small allowable grid swing if the tube was to

TABLE II

Tube	Plate Resist- ance (ohms)	Plate Volt- age	Grid Bias	Load (ohms)	Frequ- ency (Approx.)	Type "In- sulation"	No.
CX 371A	1800	135	-16½	1,811	3400	Capacity	60
"	"	"	"	1,811	500	Transformer	74
"	"	"	"	3,600	4300	Capacity	72
"	"	"	"	10,433	3400	"	64
"	"	"	"	100,000	3000	"	16
"	"	"	"	100,000	500	"	18
DX 120	6500	"	-20	6,393	3900	"	47
"	"	"	-21	13,286	3400	"	68
"	"	"	-19½	22,000	500	Transformer	80

operate on the straight part of its characteristic curve.

Pictures Nos. 60 and 74 for the CX 371 A tube and No. 47 for the DX 120 tube were made with the plate loads equal to the plate resistance of the tubes. An examination of the pictures shows that for loads equal to the plate resistance of the tubes, there is very little difference in the vertical components of amplitude of the three exposures on the picture. Any difference in amplitude might be explained by different amounts of diffusion for the three exposures. Picture No. 72 for the CX 371 A tube and No. 68 for the DX 120 tube were made with the plate load equal to twice the plate resistance of the tube. The amplitude of the three exposures on the picture may differ slightly, even more than the difference in diffusion might explain. The difference, however, is too small to be measured accurately. The remaining pictures, Nos. 64, 16, and 18 for the CX 371 A tube and No. 80 for the DX 120 tube show a measurable difference in amplitude for the three exposures made on each picture. The plate loads varied from approximately $3\frac{1}{2}$ to 55 times plate resistance. Pictures Nos. 16 and 80 show at least one exposure that has a vertical component of amplitude greater than the line exposure on the picture. Pictures Nos. 18 and 64 show one exposure with a smaller vertical component of amplitude than the straight line exposure.

The percentage difference in the vertical component of the larger elliptic figure and the

PLATE I_B

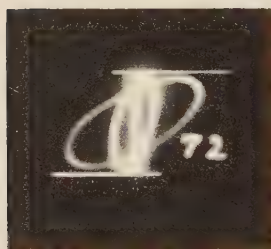
Pictures From CX 371 A Tube
Resistance of tube 1800 ohms.



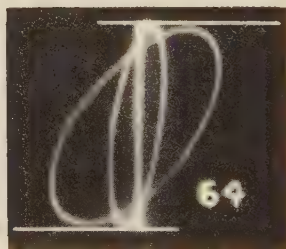
*C
+R = 1,811 ohms
#f = 3,400 cycles



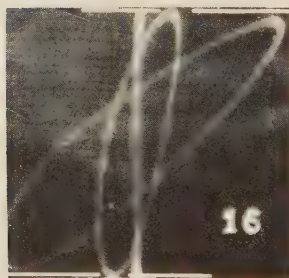
*T
R = 1,811 ohms
f = 500 cycles



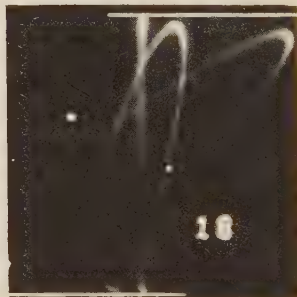
C
R = 3,600 ohms
f = 4,300 cycles



C
R = 10,433 ohms
f = 3,400 cycles



C
R = 100,000 ohms
f = 3,000 cycles



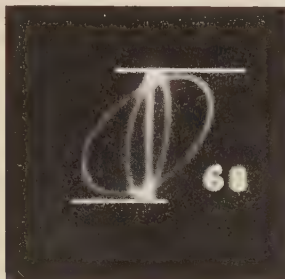
C
R = 100,000 ohms
f = 500 cycles

*C indicates capacity insulation. T indicates transformer insulation.
+R is load resistance #f is frequency in cycles (approx.).

Pictures From DX 120 Tube
Resistance of tube 6300 ohms



*C
+R = 6,393 ohms
‡f = 3,900 cycles



C
R = 13,286 ohms
f = 3,400 cycles



T
R = 22,000 ohms
f = 500 cycles

*C indicates capacity insulation. T indicates transformer insulation
+R is load resistance ‡f is frequency in cycles (approx.).

straight line exposure is given for some of the more extreme cases. Some allowance was made for greater diffusion at the ends of the vertical exposure than at the top and bottom of the elliptic exposure.

No. Picture.	Length of Vertical Component		Differ- ence.	Per cent of Dif- ference
	St. Line Exposure.	Elliptic Exposure.		
18	4.8 cm.	4.5 cm.	0.3 cm.	6+
64	3.6 cm.	3.5 cm.	0.1 cm.	3-
80	4.6 cm.	4.8 cm.	0.2 cm.	4+

No attempt was made to measure the difference in Picture No. 16. The differences are small, yet can be observed. This picture is not a duplicate of No. 18, since the frequencies are much different.

Shape of Ellipses as a Test of Distortion Due to Reflections.

Too few pictures are included in this paper to show that in practically every case where the plate load equals the plate resistance of the tube a smooth elliptic figure is obtained when capacity "insulation" is used. Due to iron distortion transformer figures are excluded. Distorted figures can be observed for all loads greater than plate resistance when capacity "insulation" is used. Part of this distortion may be due to curvature of the characteristic, and part, might be due to reflections, since all conditions except load were the same for these pictures. Theoretically two simple harmonic motions at right angles give an ellipse, the circle and straight line being special cases. If one of these simple harmonic motions is distorted in any way, the resultant figure will no longer be an undistorted ellipse. Pictures Nos. 47 and 60 show reasonably smooth elliptic figures, while all other capacity insulated figures listed are distorted.

CONCLUSIONS

In METHOD "A" distortion is assumed to be indicated by the inequality of the length of two lines in the photographs, these lines being proportional to the voltage across equal resistance sections of the load placed at the end and at the middle of the load. METHOD "B" attempts to show the same thing by introducing a phase shift. The irregularity of the shape of the "ellipses" is taken as an indication of distortion in METHOD "B" also.

All indications are that there is little if any distortion when the load, R , is made equal to R_p , the resistance of the tube. When the load is $2R_p$ there is perhaps a slight distortion, not greater than 5%. When the load is many times R_p there is noticeable distortion.

If this distortion is due to reflections the line length can not be assumed to be zero. The length is $\Delta\lambda$ and the input and output impedance should match the characteristic impedance of the line.

If the distortion is not due to reflections, large loads tend, in some unknown manner, to emphasize the harmonics caused by curvature.

The writer wishes to thank Dr. R. R. Ramsey for his supervision and interest in this research. He was most considerate and helpful at all times. The writer also thanks the other members of the Physics Department staff and James Fletcher Price, a fellow student, for the interest shown and suggestions made while this work was in progress.

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